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Combustion Characterisation of Individual Bio-oil Droplets (Extended Abstract for Flame Days 2015)

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Abstract - Single droplet combustion characteristics has been investigated for bio-oil slurries, containing biomass residue, and compared to conventional fuels for pulverized burners, such as fuel oil (start up) and wood chips (solid biomass fuel). The investigated fuels ignition delays and pyrolysis behavior was tested in a single particle reactor at conditions relevant for suspension firing (A: 1200 °C, 5.5 % O₂; B: 1200 °C, 2.9 % O₂ and C: 990 °C, 5.5 % O₂). The slurries were tested to optimize the bio-oil composition for use as an alternative power plant start-up fuel. Pyrolysis times for 5 mg bio-oil samples (app. d_p 1 mm) were generally in a similar range (1300 to 2700 ms) as fuel oil, (app 1800 ms) and wood blocks (app 2400 ms), within the 600 ms standard deviation. The 5 different bio-oil slurries samples showed considerable data variability, indicating some extent of sample heterogeneity. With respect to the ignition delay, the bio-oils were in contrast to the fuel oil (125±70 ms), associated with either a longer ignition delay or an ignition phase with sporadic gas phase ignitions (350 to 1050 ms with no stable flame), which could be a cause for concern for a start-up fuel, due to flame lift above the nozzles and thereby decreased flame stability. Most promising were oil or diesel (not palm oil) containing slurries (1 and 5) with heating values in the range of 15 MJ/kg.

1. Introduction and objectives

Pulverized fuel burner systems are often used on large thermal power plants. Start up of the burners is often performed with heavy fuel oil, that is injected into the burner as droplets in the range 50-100 µm. [1] This work will evaluate the combustion characteristics, in terms of ignition delay and pyrolysis of new biomass derived slurry fuels, more specifically bio-oil suspensions consisting of biomass residue, water and small amounts of oil or diesel.

The ignition delay before the fuel and combustion air mixture ignite, will influence the flame lift above the oil injection nozzles and could affect flame stability in the boiler room. The fuel particle/droplet residence time in the boiler is typically less than four seconds and the particles must be fully converted (i.e. completion of both pyrolysis and char burnout) within this time frame. Based on a comparison to conventional fuel fuels, optimal bio-oil composition for use as an alternative power plant start-up fuel will be identified.

2. Equipment and methodology

A single droplet/particle reactor setup was used to test the combustion characteristics of fuel oil and selected biomass residue slurry emulsions with variations in biomass residue, oil, diesel and water content. These initial tests aim at identifying important composition parameters of optimally performing emulsions.

The single particle/droplet reactor, heated by a hydrogen flame, was used to monitor the combustion performance of liquid droplets via a high speed video camera [2]. Samples were

placed on a platinum plate, then it was inserted while shielded by a protection tube, a subsequent protection tube removal swiftly exposed the sample to the hot gas at selected operating conditions, enabling a detailed study at well-controlled conditions. The monitoring enabled determination of the ignition delay, pyrolysis time and specific combustion phenomena such as oil droplet swelling (see Fig 1). Standard operating conditions were (A) 1200 °C and 5.5 % O₂, but experiments at lower O₂ (B: 1200 °C, 2.9 % O₂) and lower temperature (C: 990 °C, 5.5 % O₂) were performed for selected samples. The mass release as a function of temperature was furthermore investigated in a Netzsch STA 449 (5 °C/min in both pure N₂ and subsequently 10 % O₂)

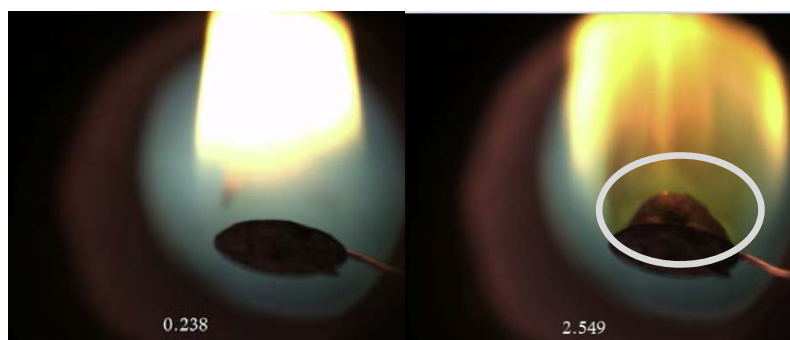


Figure 1: 15 mg Fuel oil droplet exhibiting swelling during conversion (1200 °C, 5,5 % O₂).

A wide range of fuels were investigated, including conventional diesel, fuel oil and willow wood blocks as well as several bio-oils (selected data shown in Table 1). The selected bio-oils mentioned in this abstract include a sample of pure biomass residue suspended in water (4), as well as samples spiked with diesel (1 and 3), palm oil (2) and both diesel and heavy fuel oil (5). The sample sizes investigated range from 1 mg (\approx 1.2 mm) to 20 mg (\approx 3.4 mm).

Table 1. Composition (wt. %) and heating value of selected samples

Sample	Biomass residue	Water	Oil	Palm oil	Diesel	Heating value
Fuel oil	-	-	100 %	-	-	40 MJ/kg
Diesel	-	-	-	-	100 %	40 MJ/kg
Willow	-	-	-	-	-	17 MJ/kg
Bio-oil 1	45 %	38 %	-	-	16 %	15 MJ/kg
Bio-oil 2	45 %	38 %	-	16 %	-	15 MJ/kg
Bio-oil 3	32 %	57 %	-	-	10 %	10 MJ/kg
Bio-oil 4	52 %	47 %	-	-	-	11 MJ/kg
Bio-oil 5	45 %	38 %	8 %	-	8 %	15 MJ/kg

3. Results

As illustrated by Fig. 3, the diesel and fuel oil droplets showed a short (15-200 ms) ignition delay followed by the appearance of a steady pyrolysis flame. In contrast, the bio-oil slurry samples showed longer ignition delay and sporadic gas phase ignitions (Fig. 2), before the appearance of a stable pyrolysis flame, likely due to water evaporation from the samples that contains from 38 to 57 wt.% H₂O. No clear connection between sample mass and ignition delay was seen, consequently a sample average and standard deviation has been estimated. Considerable scatter in ignition delay were seen, likely due to sample heterogeneity. An especial poor performance was seen for bio-oil samples with low heating values (3 and 4) or containing high boiling oil species, such as palm oil (bio-oil 2). This illustrates the importance of a reasonable amount of low temperature release of volatiles at the ignition time. Lower gas temperatures (990 °C) significantly increase the ignition time (fuel oil from 125±70 to 410±175 ms and bio-oil 1 from 350±245 to 2870±835 ms), while a limited effect on ignition time was seen for a low (2.9 % O₂) oxygen concentration (fuel oil 115±55 ms and bio-oil 1 380±105 ms).

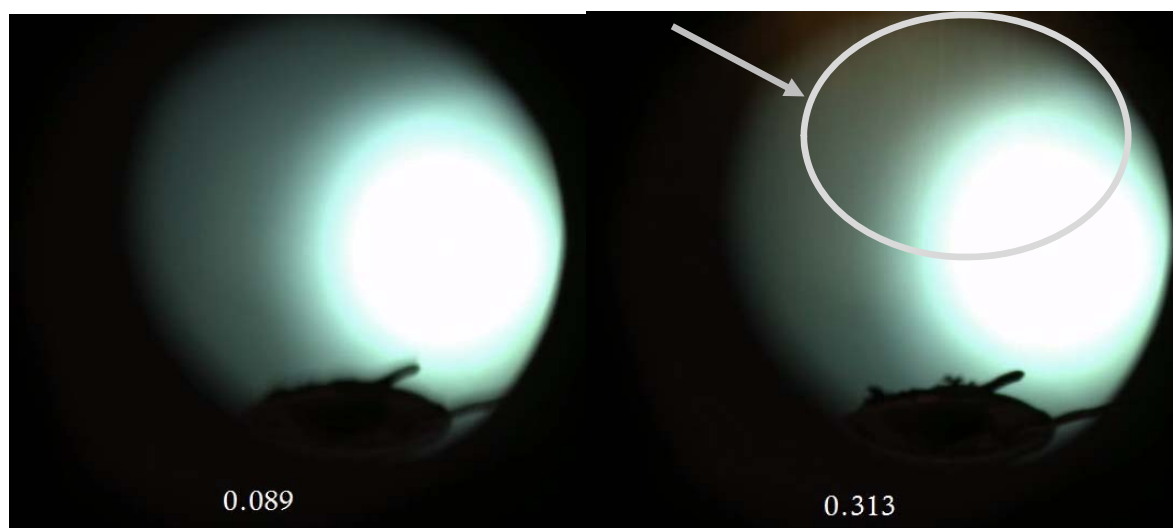


Figure 2: 5.7 mg bio-oil 3 droplet before ignition (left) and during sporadic ignition (right) before stable pyrolysis (Condition: 1200 °C, 5,5 % O₂).

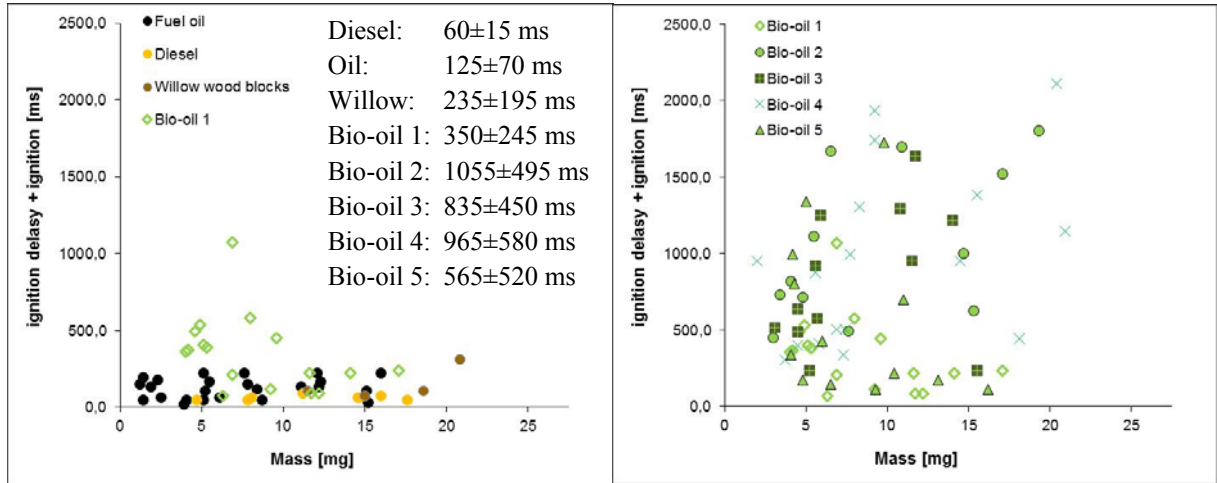


Figure 3. Total time before a stable pyrolysis flame begins (i.e. ignition delay and sporadic gas phase ignitions). Conditions: 1200 °C, 5,5 % O₂, 1.6 m/s).

Following the ignition phase a stable flame is formed by combustion of pyrolysis gases. As illustrated by Fig. 4 the duration of the pyrolysis phase was clearly mass dependent (as opposed to the ignition data). Pyrolysis times are generally associated with considerable uncertainties, as seen by standard deviations in the range 600 ms (estimated based on the difference between the individual measurements and the trendline, equation 1).

$$\sigma = \sqrt{\frac{1}{N-1} \cdot \sum (x_i - x_{trend})^2} \approx \sqrt{\frac{1}{N-1} \cdot \sum (x_i - \mu)^2} \quad \{1\}$$

A short pyrolysis duration is seen for pure diesel, while the 5 mg bio-oil samples (app. d_p 1 mm) display a wide range of pyrolysis times (from 1300 to 2700 ms), but they are generally in a range similar to heavy fuel oil (app 1800 ms) and wood blocks (app. 2400 ms). The longest pyrolysis is seen for the relative swift igniting bio-oil 1, but it's still completing its pyrolysis in a time range similar to wood blocks. Lower temperatures (990 °C) yields somewhat higher durations, as illustrated by fuel oil (2800 ms compared to 1800 ms).

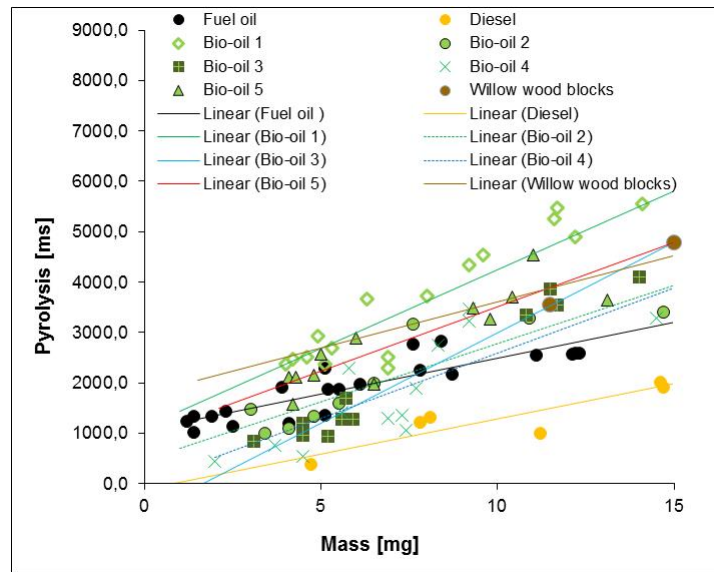


Figure 4. Pyrolysis duration at 1200 °C, 5,5 % O₂, 1.6 m/s).

The full drawn lines are linear trend-lines of the datasets

4. Conclusions

In conclusion the investigated bio-oils showed a prolonged ignition delay, with sporadic gas phase ignitions (from 350 to 1050 ms), most pronounced for samples without diesel or with high boiling oils (palm oil), while bio-oil spiked with diesel could possibly work as a start-up fuel in an oil burner, despite the higher expected flame lift. The sample sizes investigated (1 mg (\approx 1.2 mm) to 20 mg (\approx 3.4 mm)) were approximately a factor 10 larger than the fuel in pulverized fuel systems and the associated burners ($< 100 \mu\text{m}$ [1]), but this should only affect the pyrolysis duration, which was similar to fuel oil and wood blocks, indicating a potential as supplementary main fuel. The developed procedure for single droplet combustion studies provides a swift and flexible way for testing combustion behavior of liquid fuels.

Notation

σ	Standard deviation [ms]	N	Sample size [-]
μ	Population mean [ms]	x_i	Population data [ms]

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